CH5 RADIOACTIVITY

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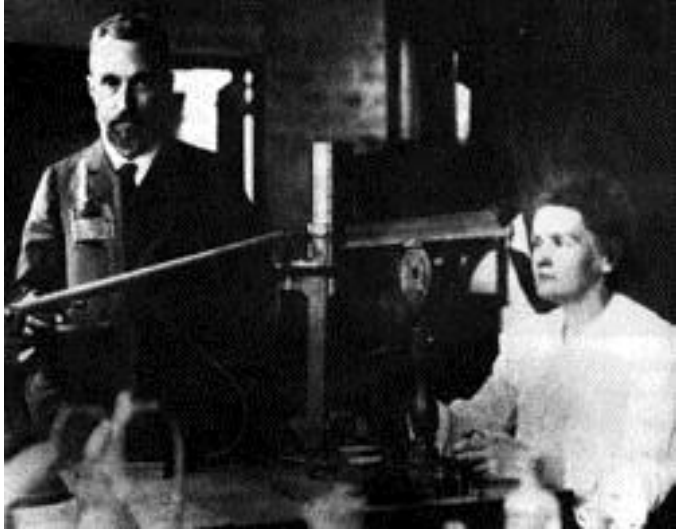
HENRI BECQUEREL

(1852-1908)

FRENCH PHYSICIST Henri Becquerel was one of the first nuclar scientists. He worked in Paris, where, in 1896, he accidentally discovered the phenomenon of radioactivity in uranium. Becquerel's discovery of radioactivity was followed up by Polishborn French physicist Marie Curie and her husband pierre. Becquerel developed the work of German physicist Wilhelm Rontgen (1845-1923), who discovered X-rays. An interest in photography helped Becquerel to discover the link between radioactivity, light, and magnetism. Becquerel also performed important research on the absorption of light and the phenomenon of phosphorescene.



Pierre Curie was already a famous scientist before he married Marie Sklodowska in 1895. they discovered radium and polonium. For their groundbreaking research in radioactivity, the couple were awarded the 1903 Nobel Prize in physics. It was Marie Curie who coined the term "radioactivity", and in her honor, the 1910 Radiology Congress chose the curie as the basic unit of radioactivity. Pierre died from being run over by a horse drawn wagon, but Marie continued their research, and was eventually awarded a second Nobel Prize, the 1911 prize for Chemistry. She died in 1934, suffering from pernicious anemia which had undoubtedly been the result of years of radiation exposure.

The nuclear force is responsible for binding protons and neutrons into atomic nuclei. Neutrons and protons are affected by the nuclear force almost identically. Since protons have charge +1 e, they experience a strong electric field repulsion (following Coulomb's law) that tends to push them apart, but at short range the attractive nuclear force overcomes the repulsive electromagnetic force.

Radioactivity defined as the spontaneous emission of particles (alpha, beta) or energy (gamma), or both at the same time, from the decay of certain nuclides, due to an adjustment of their internal structure. Radioactive decay occurs in unstable atomic nuclei – that is, ones that don't have enough binding energy to hold the nucleus together due to an excess of either protons or neutrons.

It comes in three main types – named alpha, beta and gamma for the first three letters of the Greek alphabet.

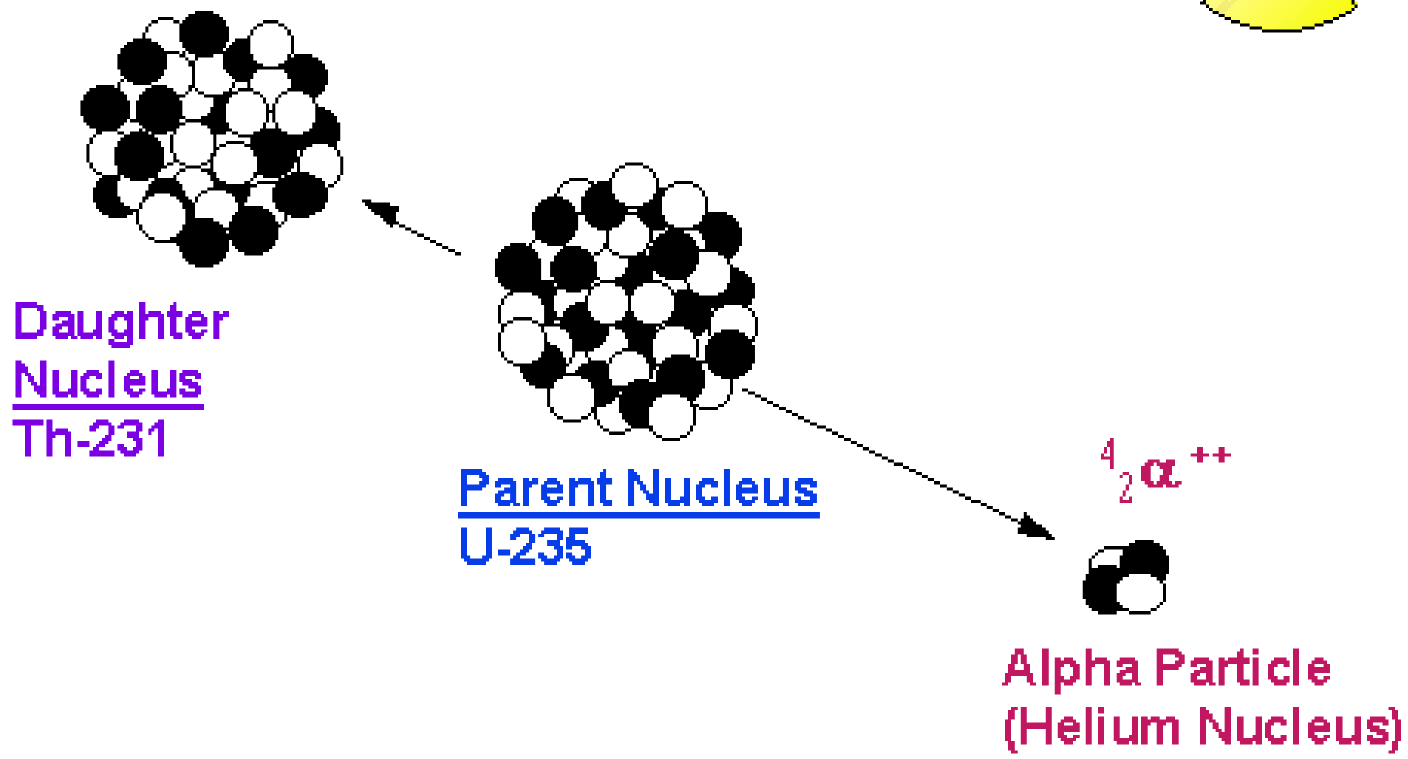
Radioactivity can be natural or artificial. In natural radioactivity, the substance has radioactivity in the natural state.
All elements have at least some isotopes that are radioactive. All isotopes of heavy elements with mass numbers greater than 206 and atomic numbers greater than 83 are radioactive.

In artificial radioactivity, the radioactivity has been induced by irradiation.

There are several ways in which unstable nuclei undergo radioactive decay:

•Alpha decay, which the emission of a helium-4 nucleus containing two protons and two neutrons. This is the least penetrating form of radiation. It is stopped by the dead layer of skin and so does no harm when outside the body. But it is the most damaging form of radiation when deposited inside the body.

Alpha Particle Radiation



Many heavy nuclei emit an energetic alpha particle when they decay. For instance uranium-238 decays into thorium-234 with a half-life of almost 4.5 billion years by emitting an alpha particle:

92-uranium-238 ====> 90-thorium-234 + alpha particle (nucleus of 2-helium-4)

•Beta decay, which the emission of an electron or a positron (a particle identical to an electron except that it has a positive electrical charge). Like alpha decay, beta decay occurs in isotopes which are “neutron rich” .

When a nucleus ejects a beta particle, one of the neutrons in the nucleus is transformed into a proton.

When we talk about the beta plus decay a proton decays into a neutron, a positron (the antiparticle of the electron) and a neutrino. The positron and the neutrino are emited. The radioactive particle is the positron

Beta particles have a single negative charge and weigh only a small fraction of a neutron or proton. As a result, beta particles interact less readily with material than alpha particles. Beta particles will travel up to several meters in air, and are stopped by thin layers of metal or plastic.

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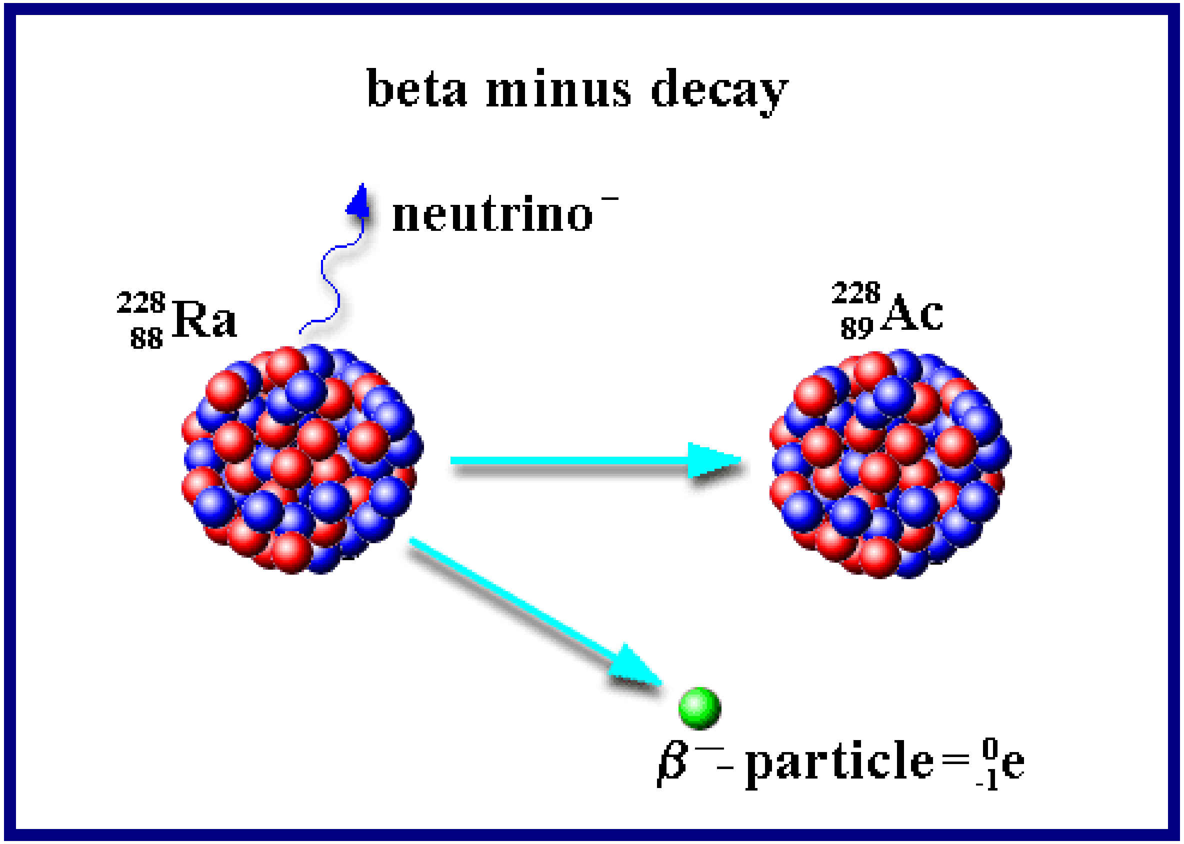
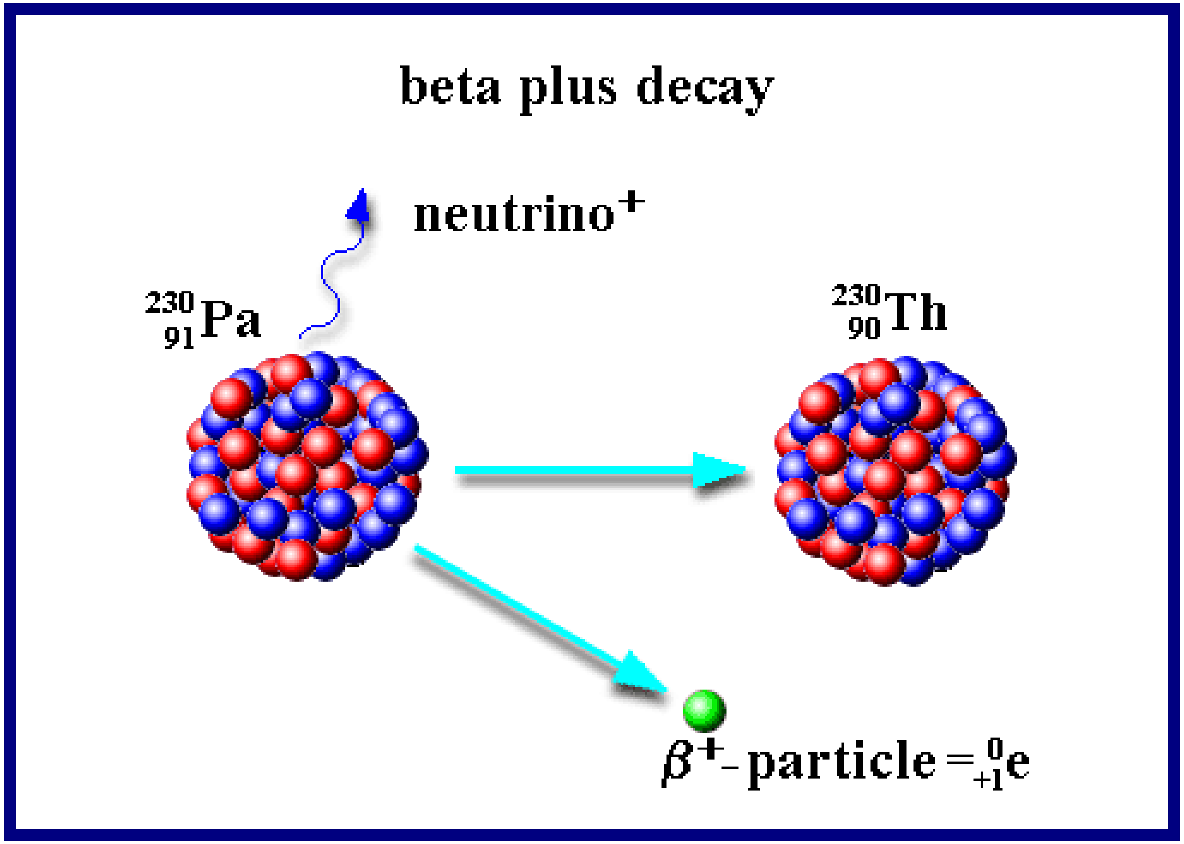
In beta decay, the atomic number increases by one if an electron is emitted or decreases by one if a positron is emitted. For instance thorium-234, which is the decay product of uranium-238, in turn beta-decays into protactinium-234 by emitting an electron:

90-thorium-234 ====> 91-protactinium-234 + beta particle (electron)


beta minus decay
neutrino⁻
$^{228}_{88}Ra$
$^{228}_{89}Ac$
β^-- particle = $^{0}_{-1}e$



beta plus decay
neutrino+
$^{230}_{91}Pa$
$^{230}_{90}Th$
β^+- particle = $^{0}_{+1}e$

The nuclei that result from radioactive decay may themselves be radioactive. Therefore, some radioactive elements have decay chains that may contain many radioactive elements, one derived from the other.

Electron capture, which is the capture by the nucleus of an electron from among the ones whirling around it. In effect, the electron combines with a proton to yield a neutron.

Spontaneous fission, which is the fission of a heavy element without input of any external particle or energy.

spontaneous fission, or electron capture, it does not cause the transmutation of the nucleus into another element.

Often, there is still excess residual energy in the nucleus after the emission of a particle or after electron capture. Some of this residual energy after radioactive decay can be emitted in the form of high-frequency electromagnetic radiation, called gamma rays

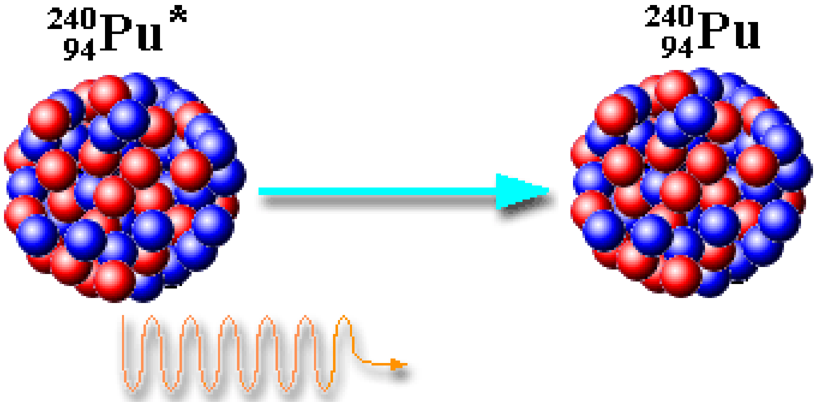
It should be noted that the emission of gamma rays does not change the mass number or atomic number of the nucleus — that is, unlike radioactive decay by emission of particles,

"The gamma ray is identical in nature to light or microwaves, but of very high energy.

Like all forms of electromagnetic radiation, the gamma ray has no mass and no charge. Gamma rays interact with material by colliding with the electrons in the shells of atoms. They lose their energy slowly in material, being able to travel significant distances before stopping. Depending on their initial energy, gamma rays can travel from 1 to hundreds of meters in air and can easily go right through people.

It is important to note that most alpha and beta emitters also emit gamma rays as part of their decay process. However, there is no such thing as a "pure" gamma emitter.

gamma decay

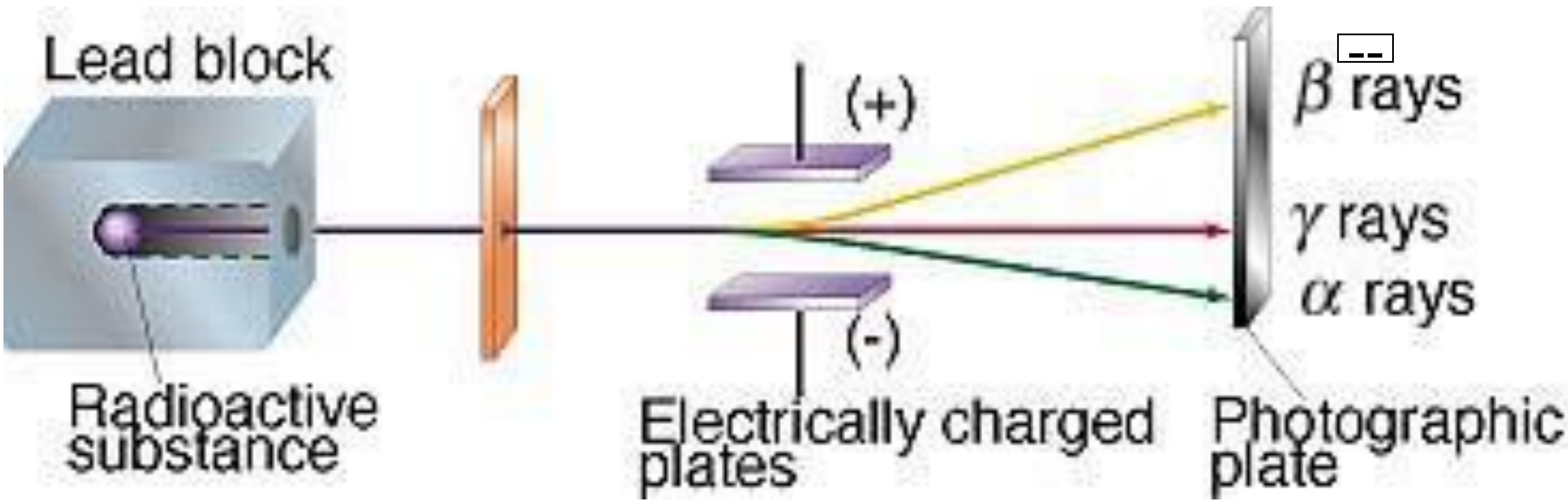


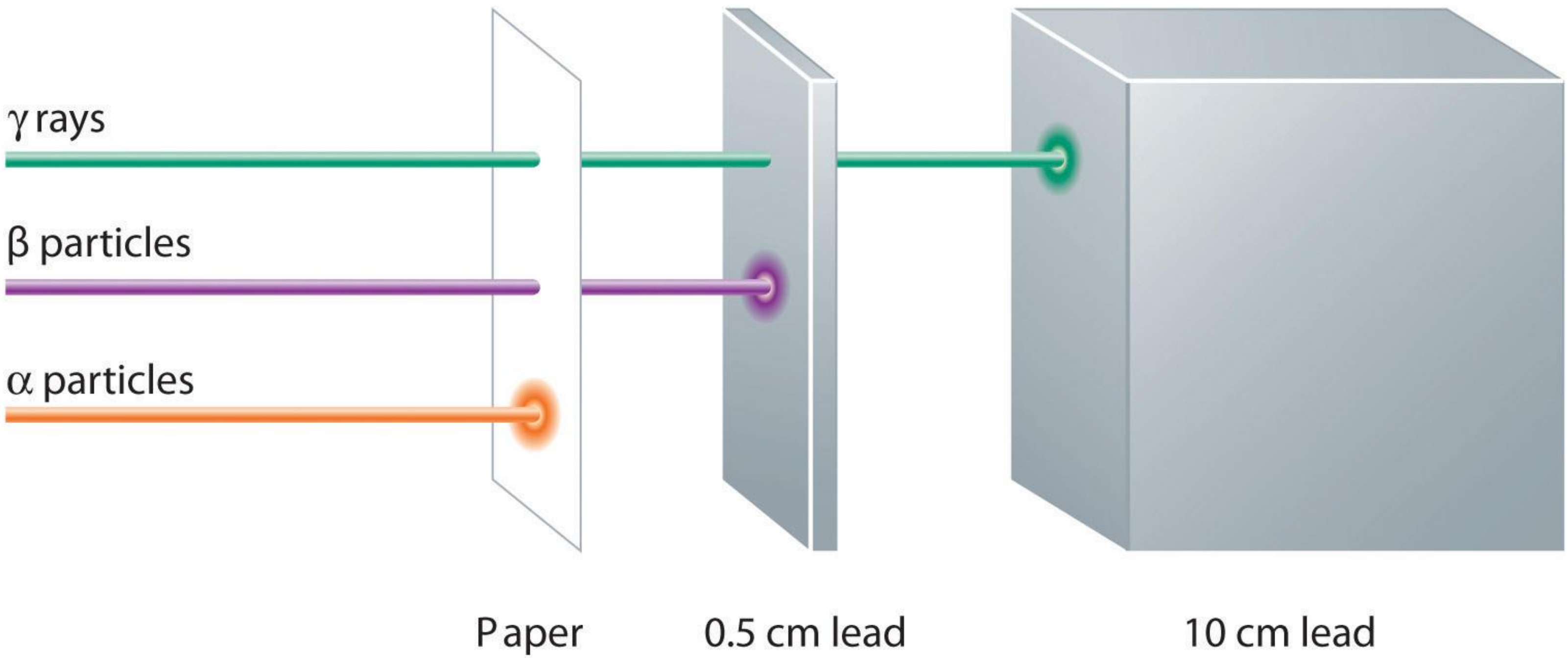
γ-radiation: high-energy electromagnetic waves

The following table shows a comparison between alpha particle, beta particle and gamma ray

Type of Radiation	Alpha particle	Beta particle	Gamma ray
Symbol	α or ${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$	β or β^{-}	γ
Mass *(a.m.u)*	4	1/2000	0
Charge	+2	-1	0
Speed	slow	fast	very fast (speed of light)
Ionising ability	high	medium	0
Penetrating power	low	medium	high
Stopped by:	paper	aluminium	lead

RADIATION AND ITS CHARGE




γ rays
β particles
α particles
Paper
0.5 cm lead
10 cm lead

BACKGROUND RADIATION

RADON GAS

HOSPITALS

NUCLEAR EXPLOSIONS

COSMIC RAYS

Human beings are constantly exposed to low levels of ionizing radiation from natural sources. This type of radiation is referred to as ***natural background radiation***, and its main sources are:

- Visible light, ultraviolet light and infrared light (sunlight). Radioactive materials on the earth's surface (contained in coal, granite, etc.).

- Radioactive gases leaking from the earth (radon).

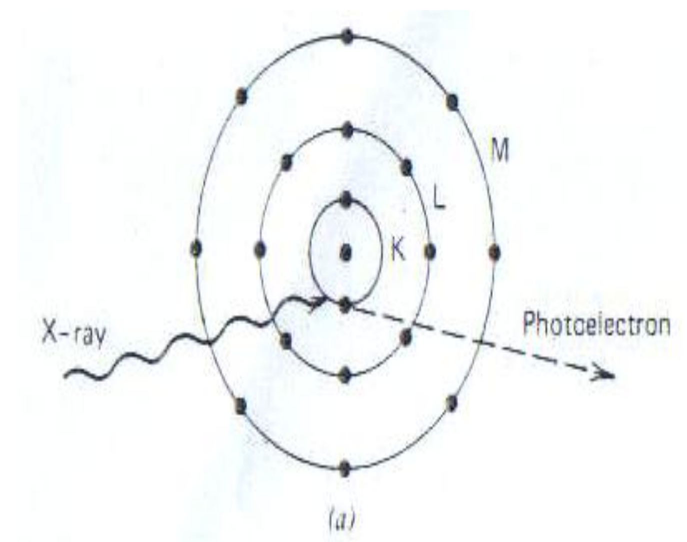
- Cosmic rays from outer space entering the earth's atmosphere through the ionosphere.

Interaction of radiation with matter:

γ radiation interact with matter through a variety of alternative mechanisms. The three most important mechanisms are the photoelectric effects, Compton effects and pair production.

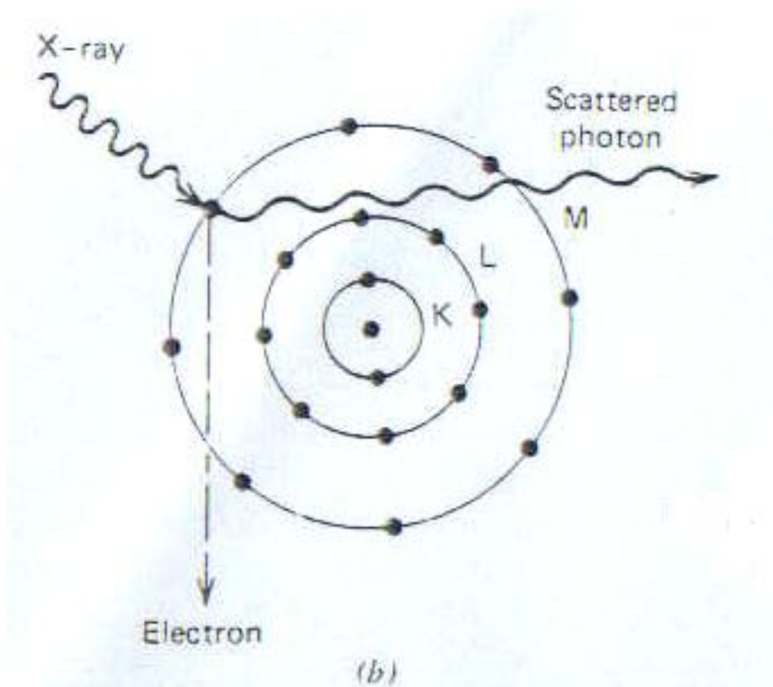
1- Photoelectric effect

Collision process **between gamma rays** and **a bound atomic electron** where the photon disappears, the bound electron is ejected, and the incident energy is shared between the ejected electron and the remaining atom. **The photon energy must be greater than the atomic binding energy**.



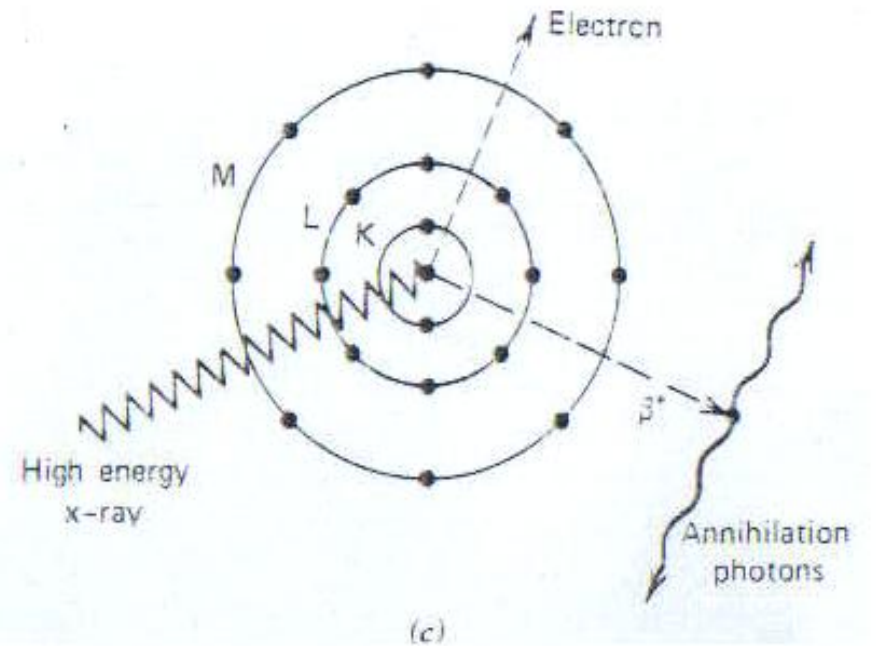
2- Compton Effect

Occurs at a quantum energy of about 10 KeV. In this case a Compton electron is ejected from the atom and is accompanied by the scattering of a secondary γ-radiation. However, this latter radiation has quantum energy lower than that which was originally absorbed.



3- Pair production

A collision process for gamma rays with energies greater than 1022-keV (two electron masses) where an electron /positron pair is produced. A heavy nucleus must be present for pair production.



Half-life is the time required for the quantity of a radioactive material to be reduced to one-half its original value.

All radionuclides have a particular half-life, some of which a very long, while other are extremely short.

For example, uranium-238 has such a long half life, 4.5×10^9 years, that only a small fraction has decayed since the earth was formed. In contrast, carbon-11 has a half-life of only 20 minutes.

The radioactive decay low is exponential in nature and can be represented by

$$A = A_o e^{-\lambda t}$$

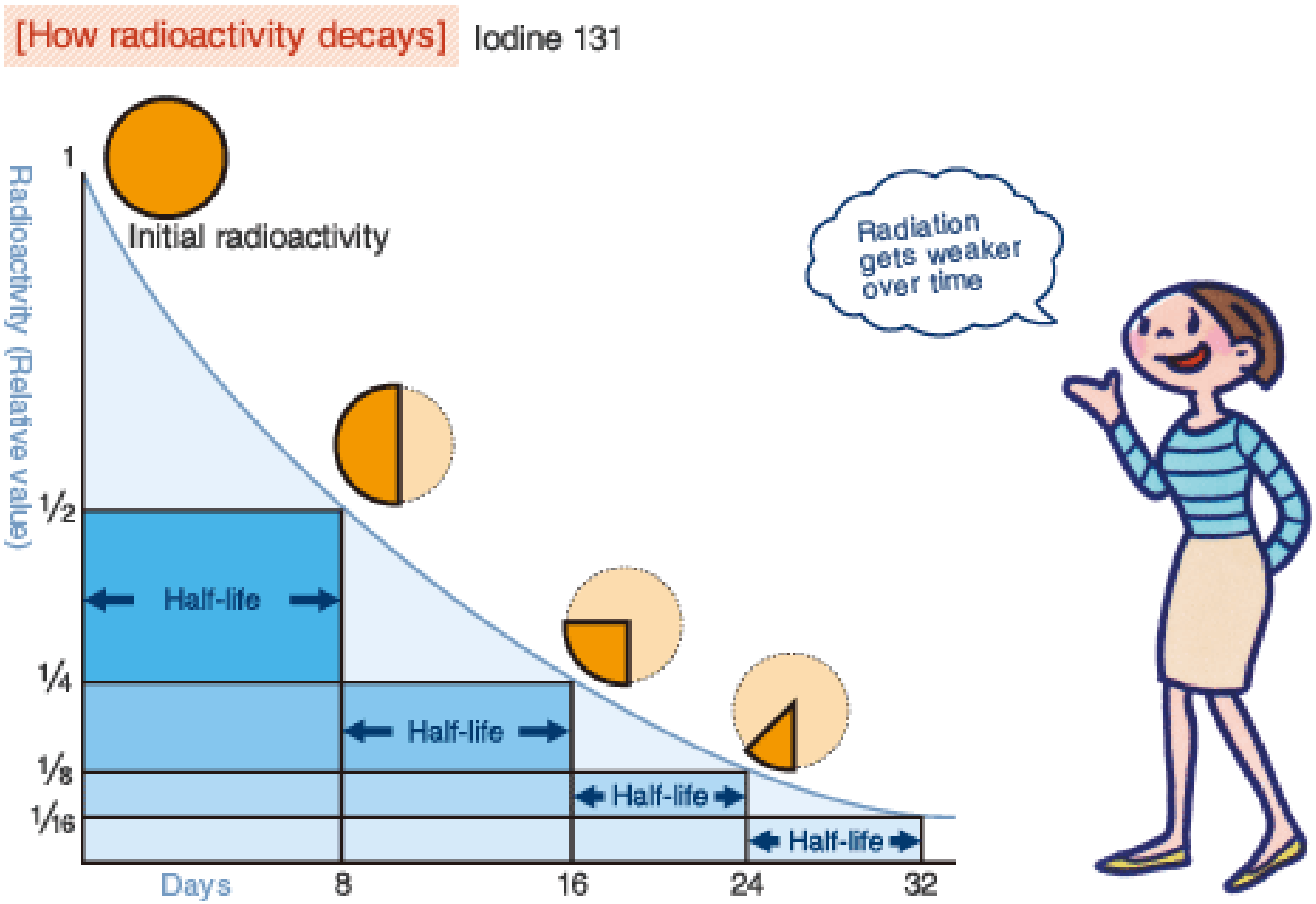
Where :

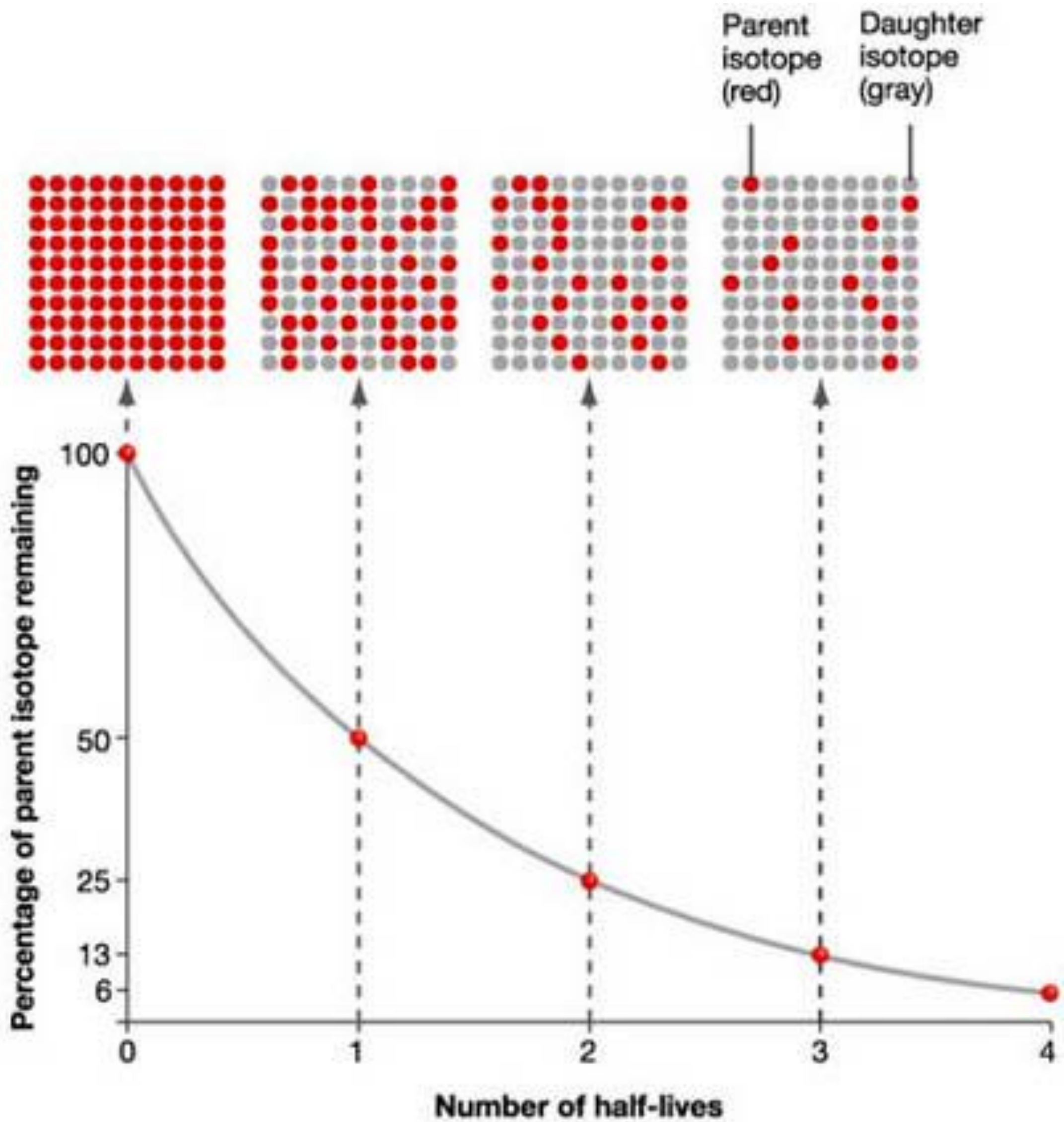
A is the activity in disintegrations per second,

Ao, is the initial activity,

λ is the decay constant and

λt is the time


[How radioactivity decays]
Iodine 131
1
Initial radioactivity
Radioactivity (Relative value)
1/2
1/4
1/8
1/16
Half-life
Half-life
Half-life
Half-life
Days
8
16
24
32
Radiation gets weaker over time


Parent isotope (red)
Daughter isotope (gray)
100
50
25
13
6
0
1
2
3
4
Percentage of parent isotope remaining
Number of half-lives

Example (4.1):

- If you have 2g of pure ^{40}K that emits $2x10^5$ β particles/ sec. what is the decay constant λ?

Solution:-

40 g of ^{40}K contain 6.02 x 10^{23} K atoms (Avogadro's number).

$$40gm \rightarrow 6.02x10^{23}$$

$$2gm \rightarrow ??????????$$

Therefore 2gm contains $\frac{2x6,02x10^{23}}{40}$

Then the activity $A = \lambda N$

Where N is the number of radioactive atoms

$$\lambda = \frac{A}{N} = \frac{2x10^5}{3x10^{22}} sec^{-1} = 6.7x10^{-18} sec^{-1}$$

Thank you for your attention